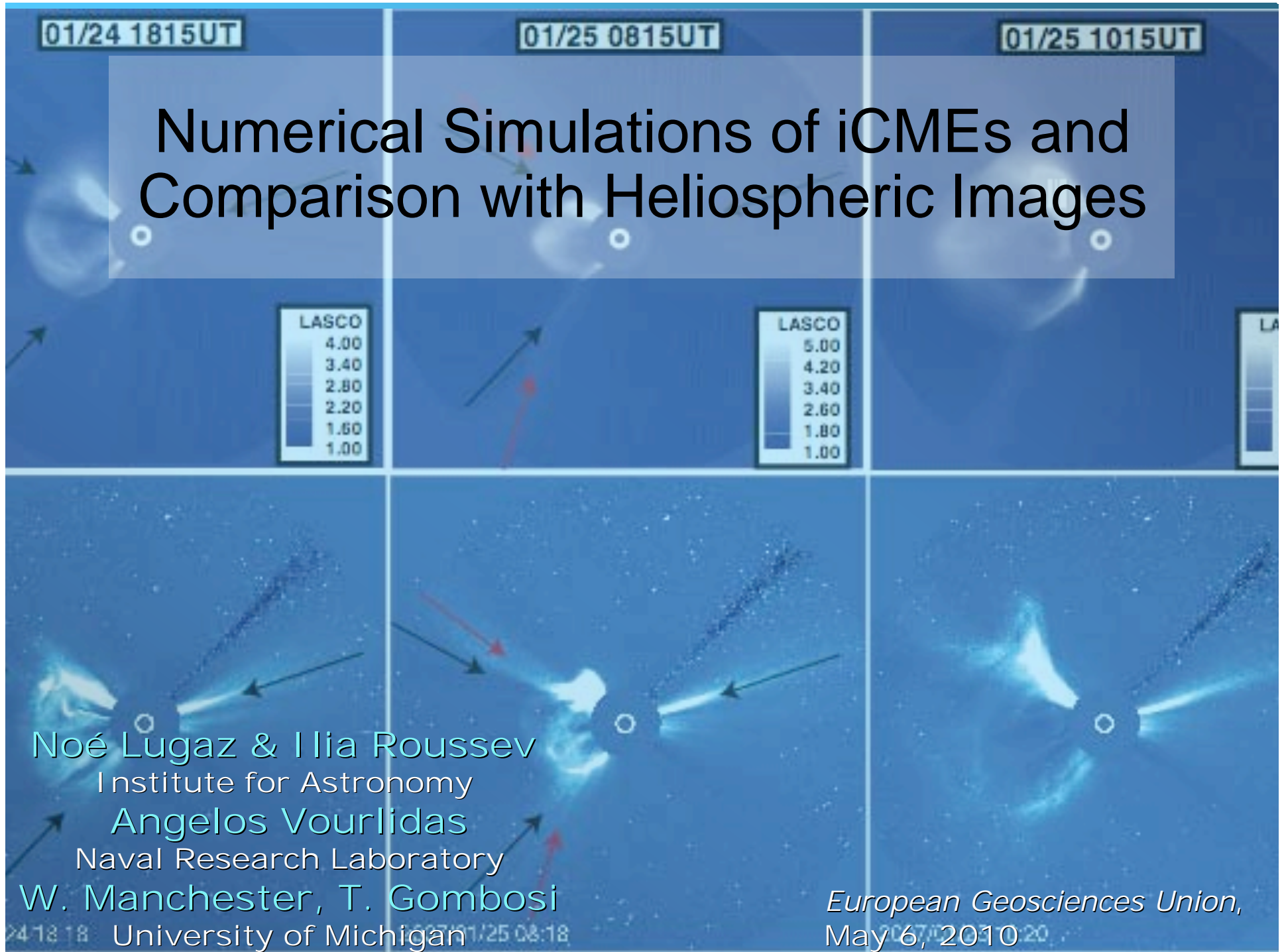


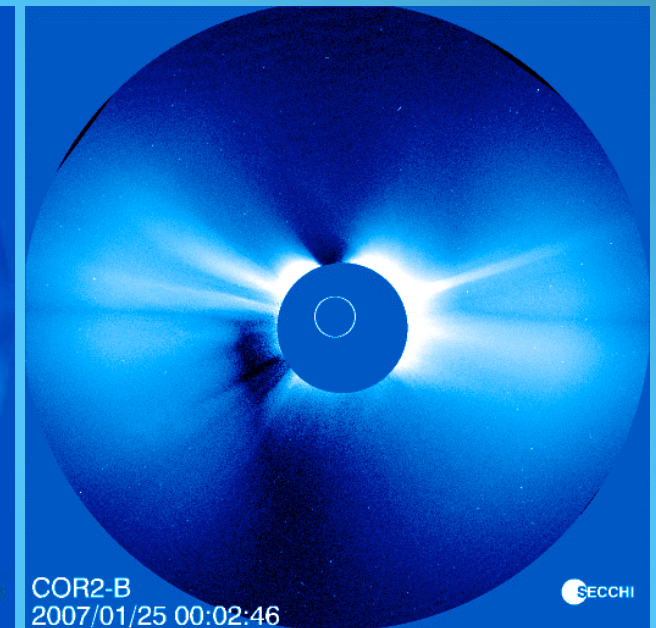
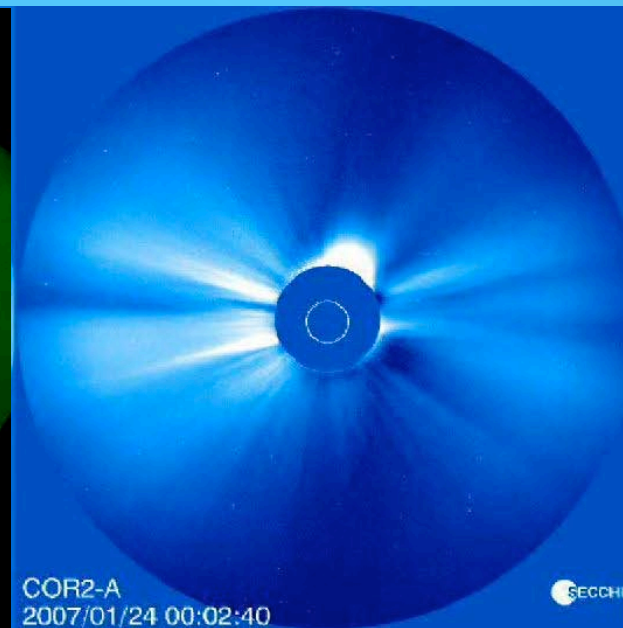
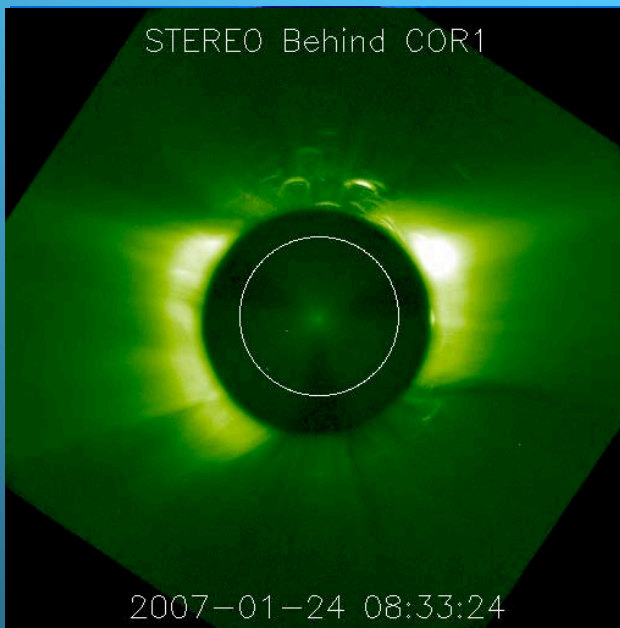
Numerical Simulations of iCMEs and Comparison with Heliospheric Images



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The 2007 January 24-26 CMEs

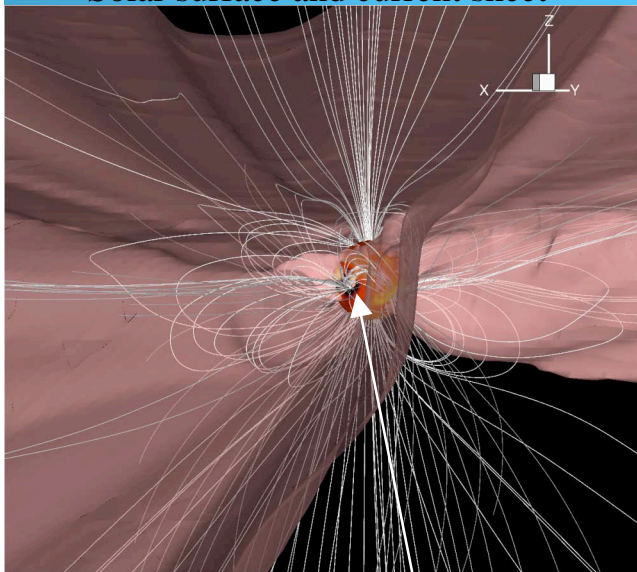
- ❁ First major CMEs observed by the SECCHI suite...
 - ... but with a 20 hour gap while the CMEs were in HI1's FOV.
- ❁ *1st CME*: 01/24 @14:03 ~700 km/s - *2nd CME*: 01/25 @06:43 ~1200 km/s
- ❁ Data gap: 01/25 06 UT to 01/26 00 UT
- ❁ Studied by Harrison et al. (2008) and Webb et al. (2009).
- ❁ Simulated by Lugaz et al. (2009) and Odstroil et al. (2009).



Simulation set-up

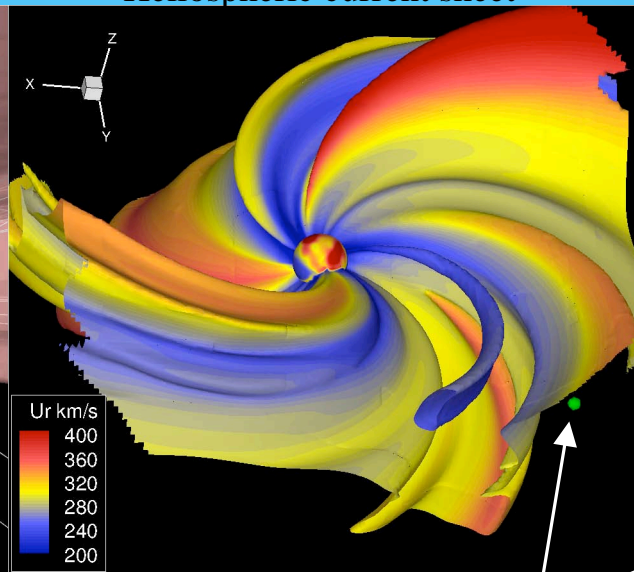
- ☉ Space Weather Modeling Framework (Univ. Michigan)
- ☉ Solar wind model of Cohen et al. (2007), out-of-equilibrium flux ropes chosen to match initial observed speed.
- ☉ From $1R_{\text{Sun}}$ to 1 AU: 40,000 4^3 blocks + 15,000 8^3 blocks ($> 10\text{M}$ cells)

Solar surface and current sheet



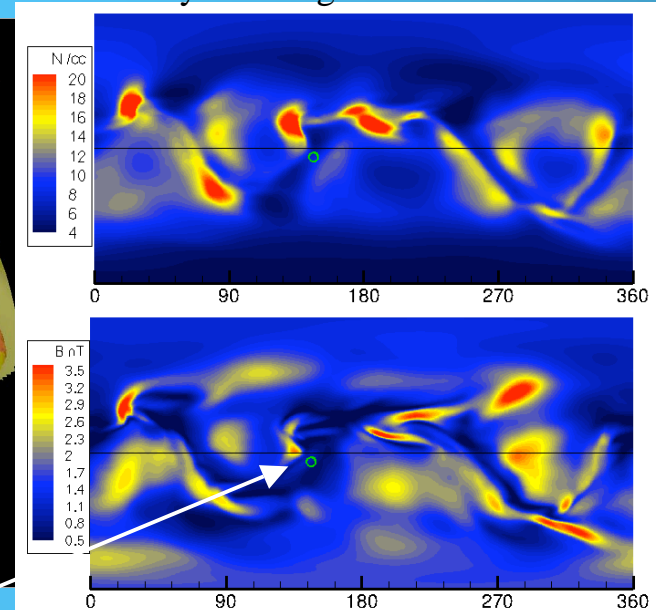
AR 940

Heliospheric current sheet



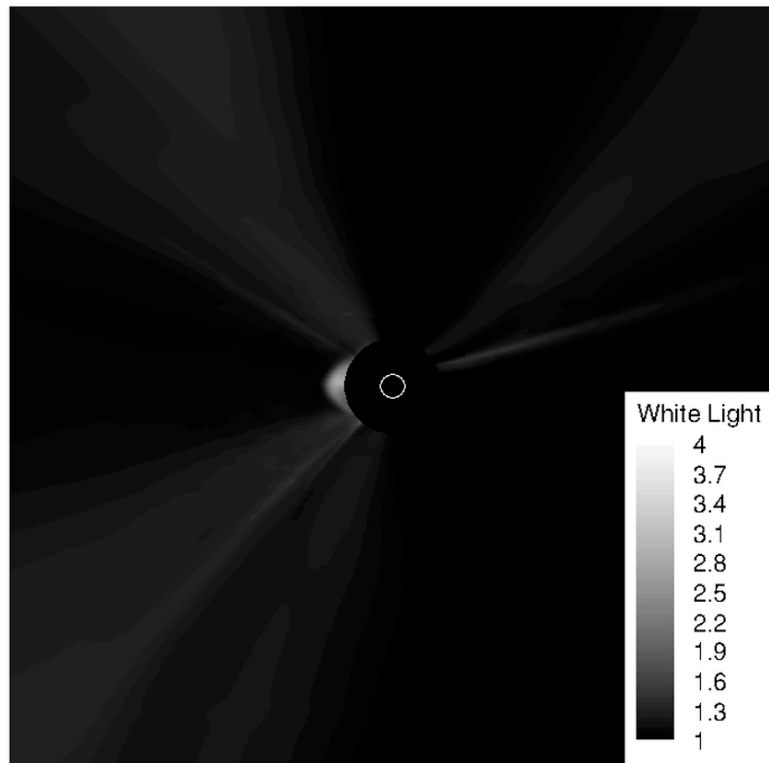
Earth (2007, January 24)

Density and magnetic field at 1 AU

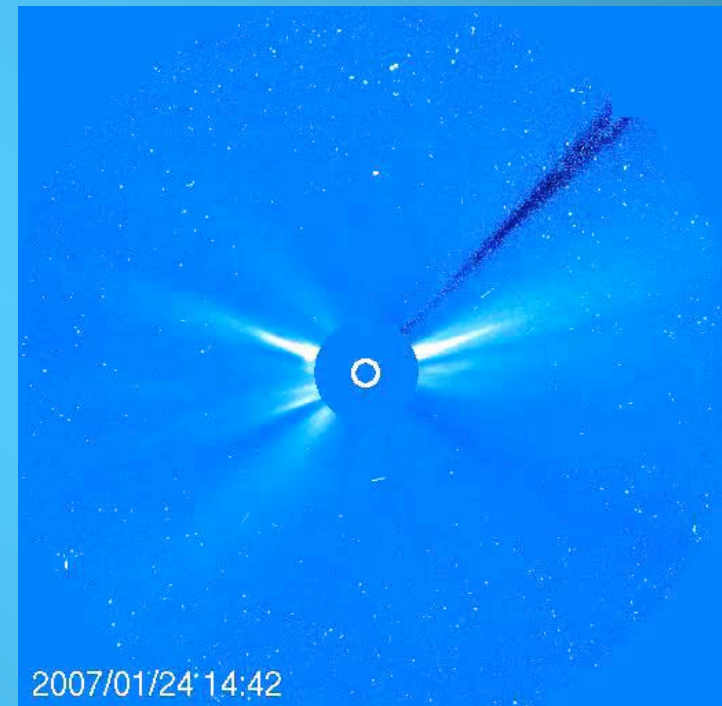


Line-of-sight images

- ☼ Simulated background is calculated by deriving the minimum image from 27 steady-state LOS images.



T = 15:00:00 since January 24, 2007 00 UT



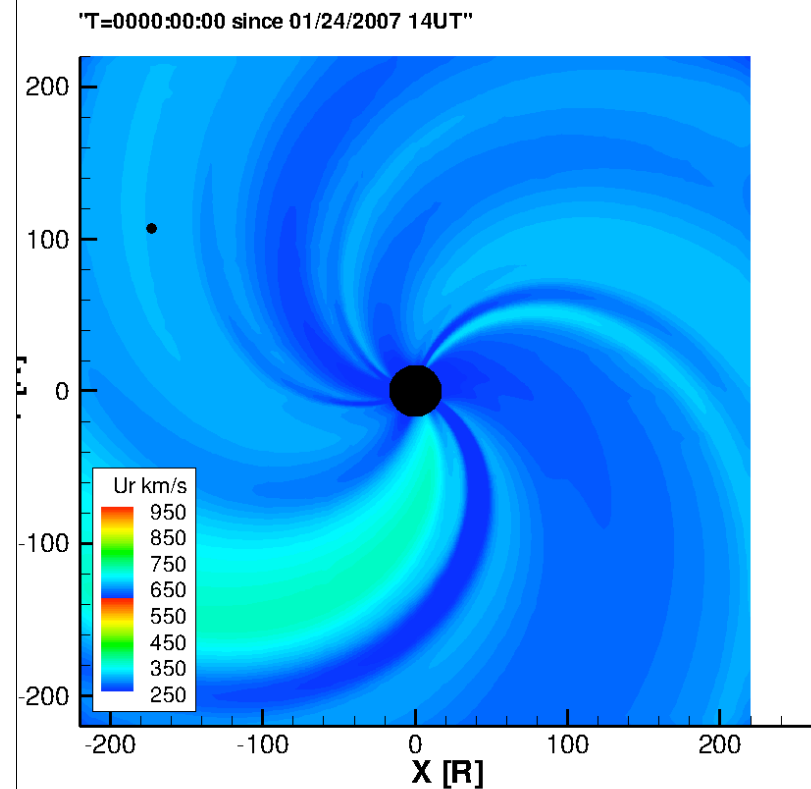
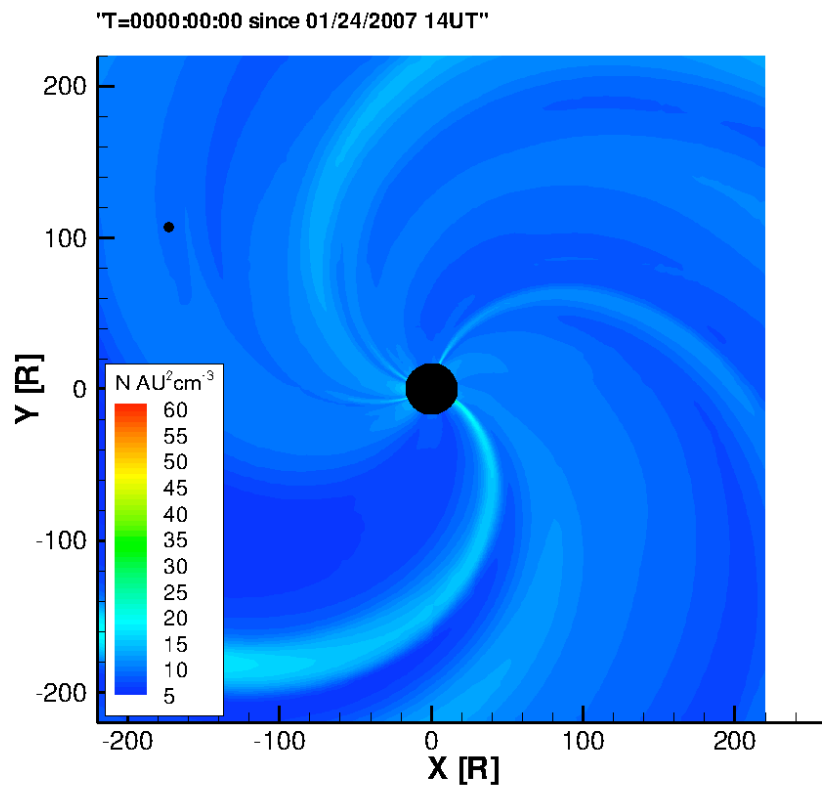
EGU

May, 6, 2010

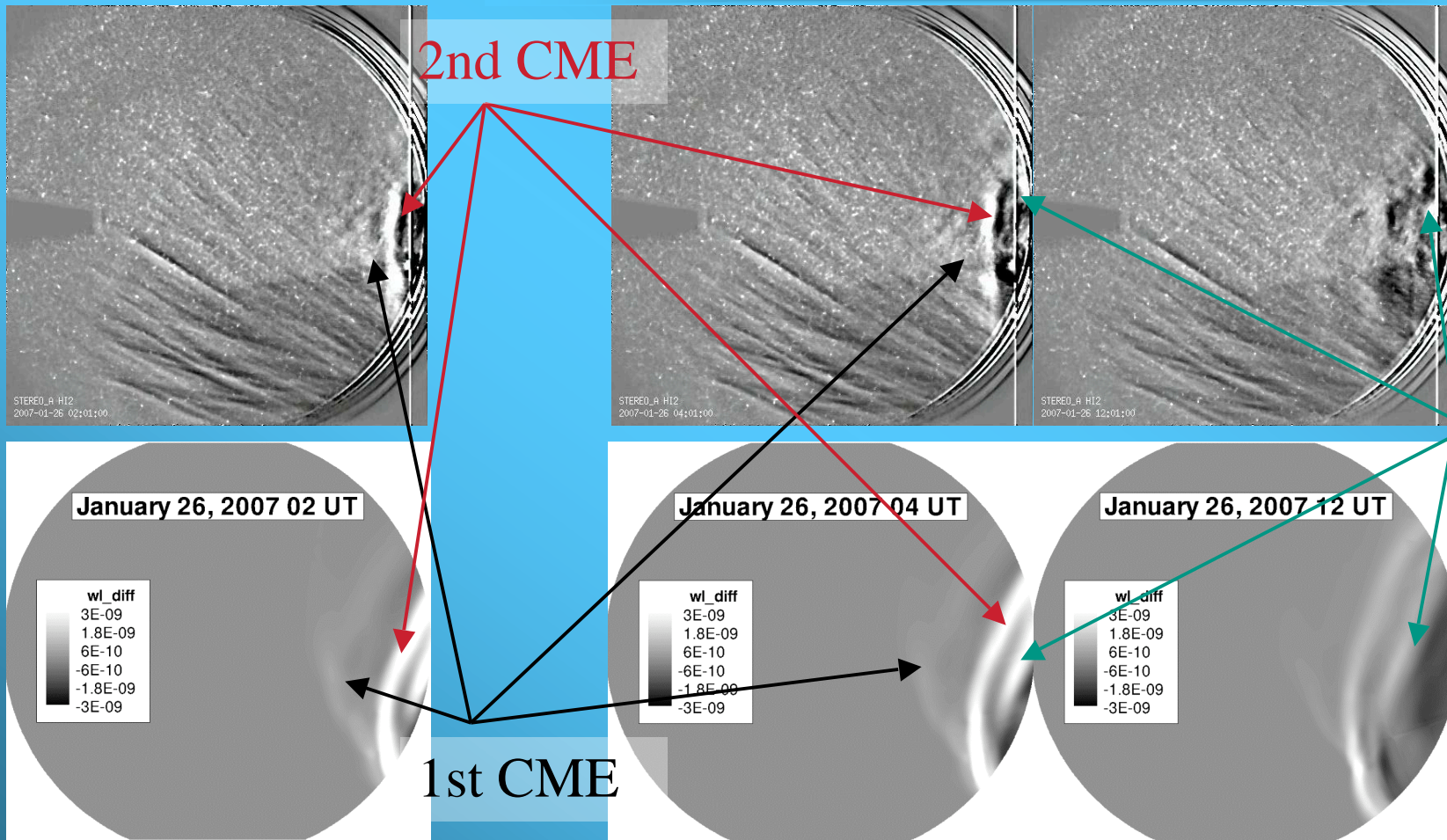
Heliospheric Evolution



- ☼ Near solar minimum: there are a number of steady structures (CIR-like).
- ☼ Interaction involves not only the 2 CMEs but also these dense streams.

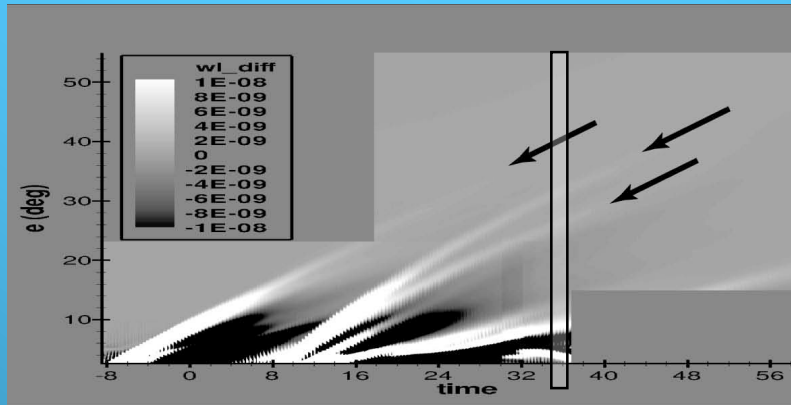


Heliospheric Imagers: what is being observed?

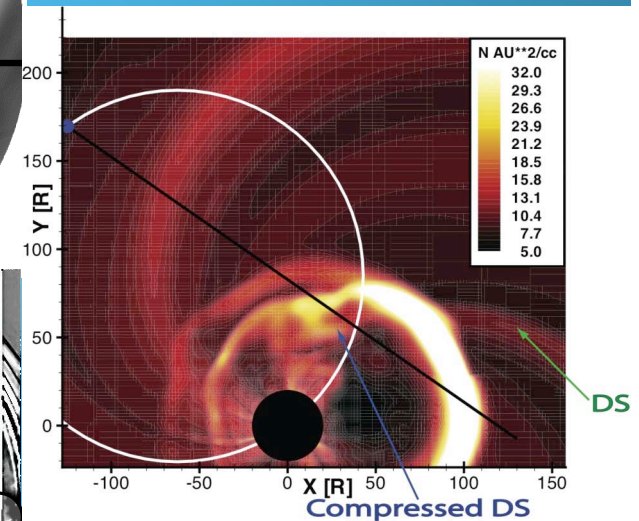
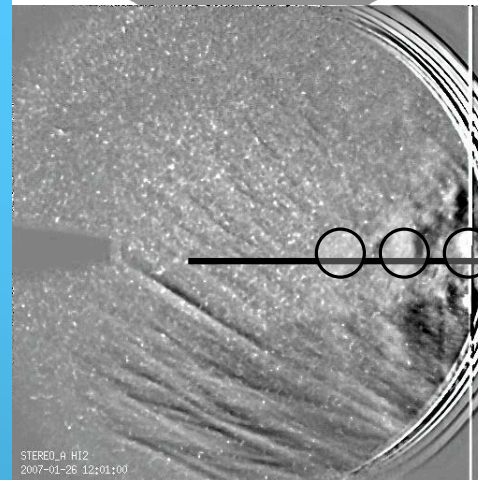
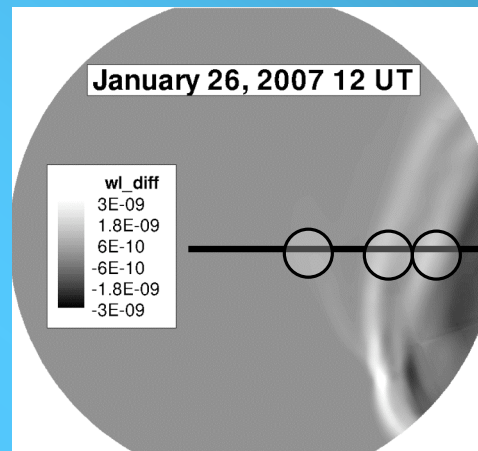
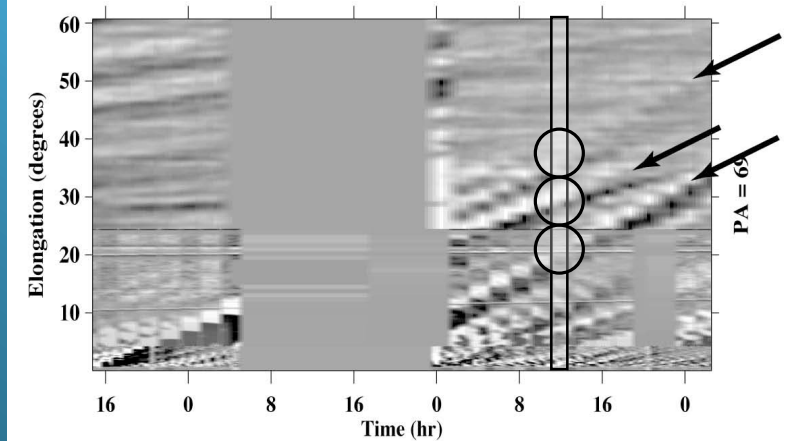


2nd CME is brighter because the leading front propagates inside the sheath of the 1st CME.
Dense stream can be identified as such in these images, because its propagation speed is different.

Time-elongation plots

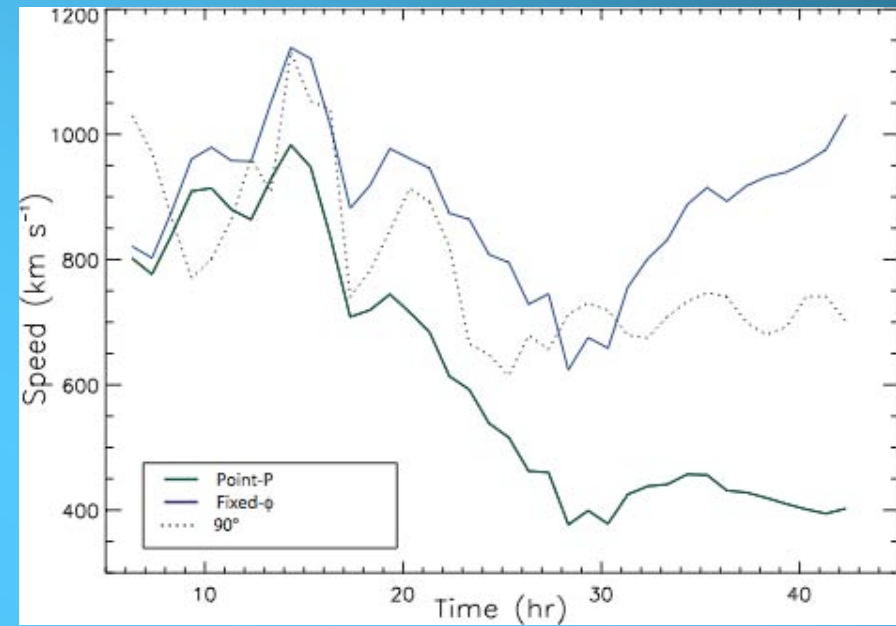
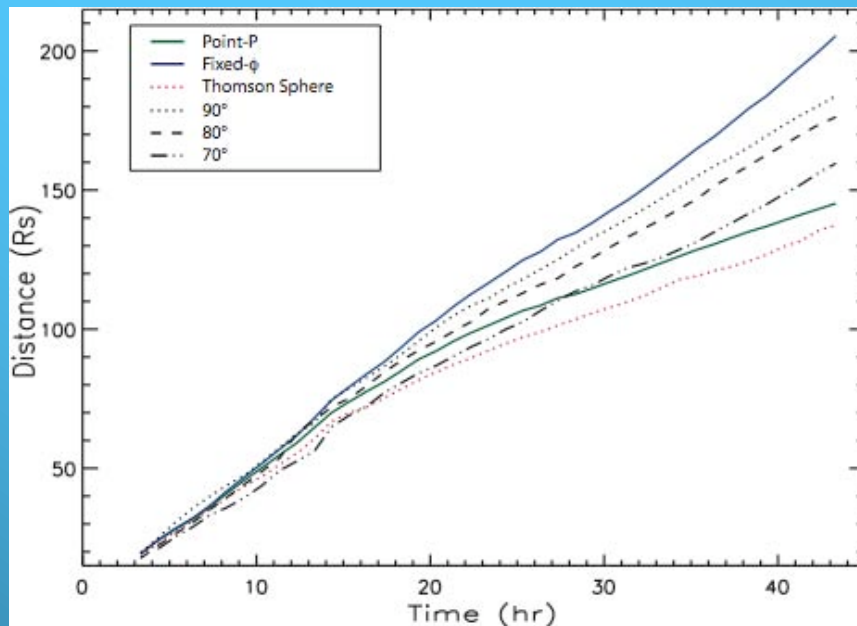


2007-1-24 to 2007-1-27



Time (from 01/25)-elongation plots for PA 69 (apparent central PA of SECCHI).

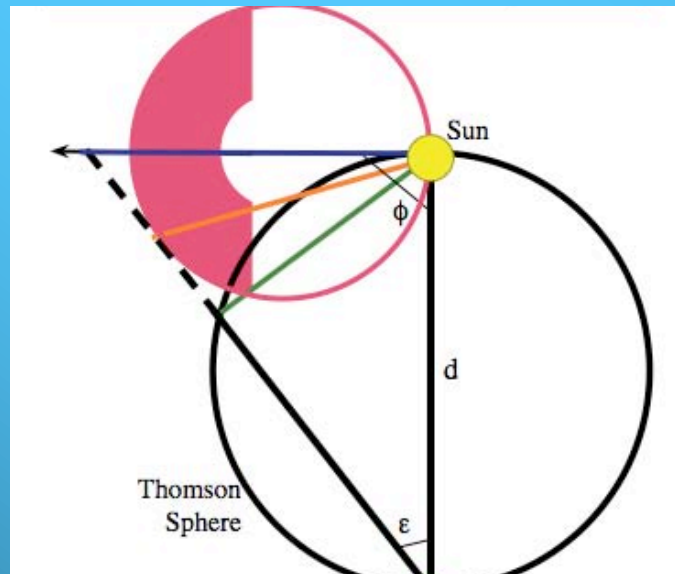
Simulations as laboratory: Testing position and velocity estimates



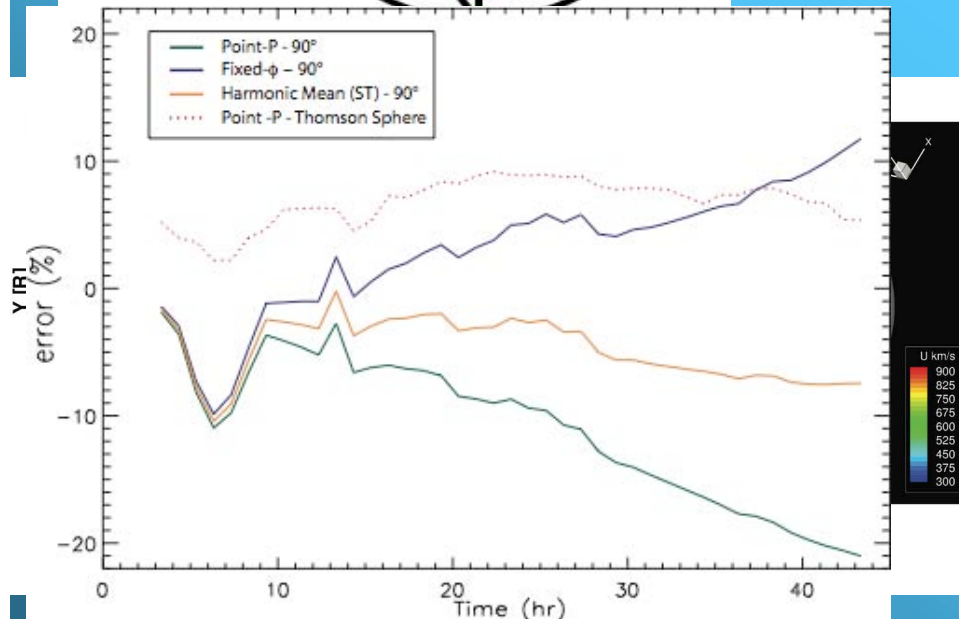
- ☼ Here testing method to derive position from elongation measurements (Kahler et al., Rouillard et al.).
 - Fixed-Phi: Approximates CME with a single point
 - Point-P: Approximates CME with an expanding sphere centered at the Sun
- ☼ Position is well determined up to 0.5 AU.
- ☼ Speed is not very well determined from existing methods, especially for wide, limb ejections past 0.5 AU.

New geometrical method to derive CME position from elongation angle

(Lugaz et al. Ann Geo, 2009)



- ☀ Instead of using single-point approximation or assuming a spherically symmetric front we use a sphere attached to the Sun.
- ☀ New assumption is good for wide CMEs (better than Point-P).
- ☀ It can be shown that:



$$r_{F\phi} = d \sin \epsilon / \sin (\epsilon + \phi)$$

$$r_{PP} = d \sin \epsilon$$

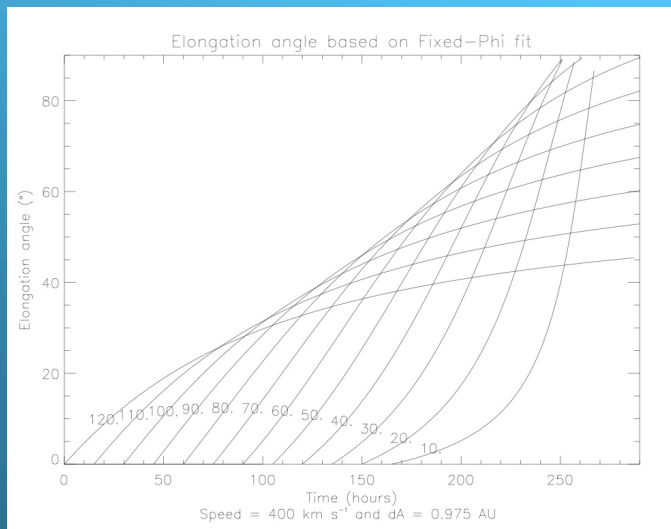
$$r = 2d \sin \epsilon / (1 + \sin (\epsilon + \phi))$$

$$1/r = .5 (1/r_{PP} + 1/r_{F\phi})$$

Simulations as controlled laboratory environment



- ☼ Testing fitting methods to derive CME direction.
 - ☼ Devised for plasma blobs/CIRs with 3 assumptions:
 - constant direction,
 - small CME width,
 - constant speed.
- stereoscopic methods: Liu (2010), Lugaz (2010) in ApJ
 statistical study or different assumption
 statistical study difficult (lack of fast CMEs)
 Simulations

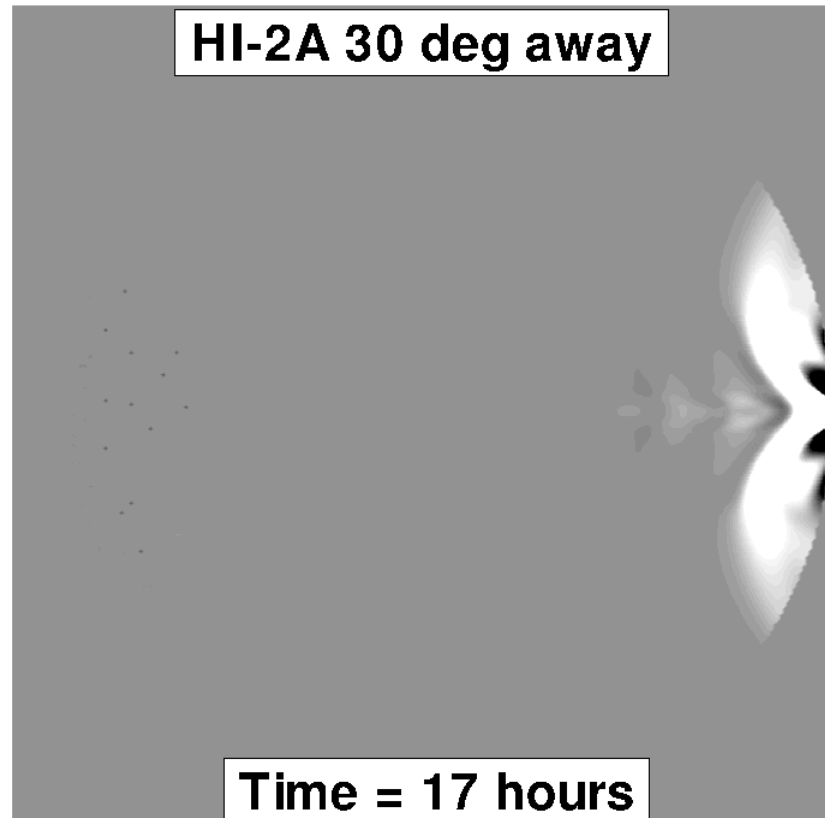


- ☼ Worst case scenario for fitting method:
 - Fast CME
 - Very wide
 - *In front of a coronal hole* (not done here)
- ☼ We do a simulation of a 800 km/s wide CME (at 20 Rs) into a solar minimum configuration (bipolar magnetic field).

Same CME from 2 different view points

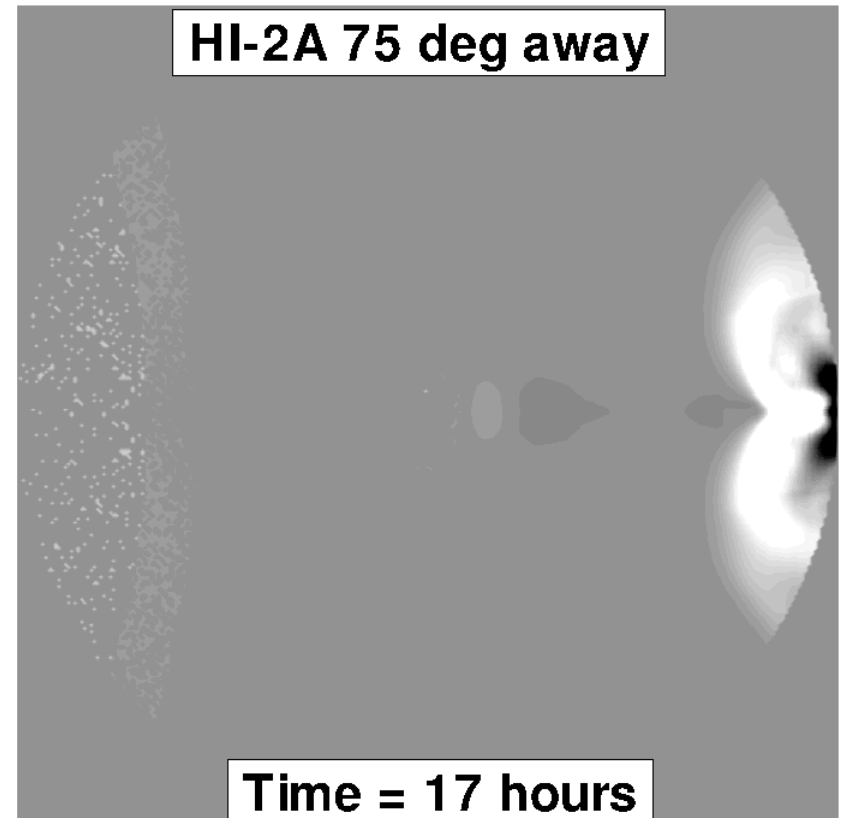


HI-2A 30 deg away



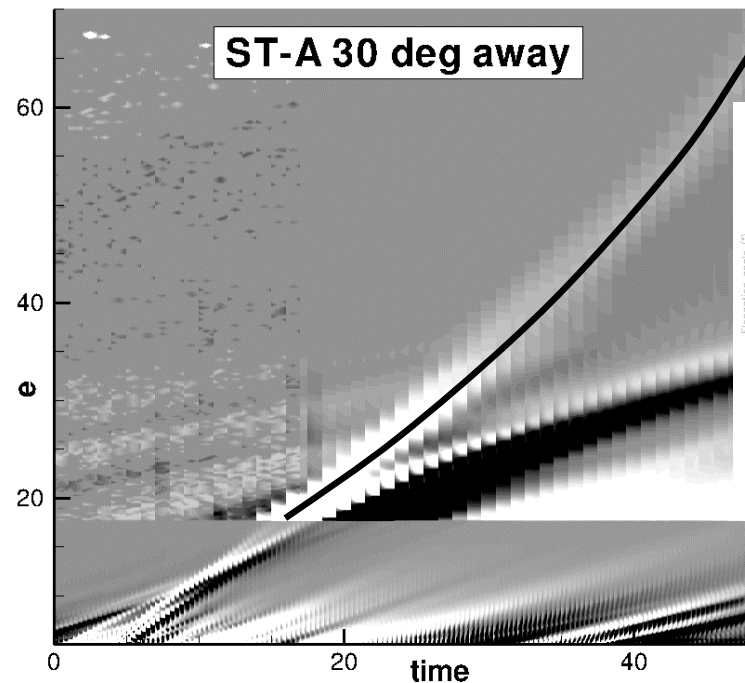
Time = 17 hours

HI-2A 75 deg away

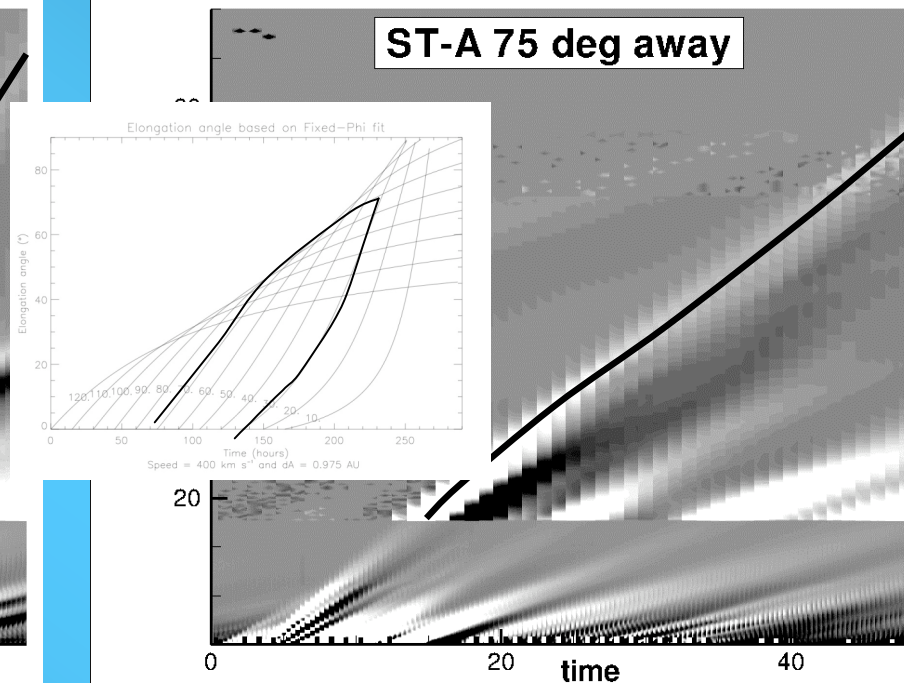


Time = 17 hours

J-maps and direction



Best fit: 619 km/s and 31°
[585-659] and [22°,45°]



Best fit: 606 km/s and 42°
[561-694] and [27°,66°]

- ⊗ "Geometrical" acceleration/deceleration not as clear as expected.
- ⊗ Good for small directions (*halo CMEs*), large underestimation of large directions (*limb CMEs*).
- ⊗ MORE at my poster tomorrow ([EGU2010-3691](#)).

Conclusion

- ☼ Simulations are an important tool in support of HI observations
- ☼ For complex events (CME-CME interaction):
 - What happened? (Lugaz et al., *Sol. Phys.*, 2009, Webb et al, *Sol Phys*, 09)
 - Testing different physical mechanisms (Lugaz et al., *Ann. Geo.*, 2009)
- ☼ To test and validate methods:
 - Simulations are like a controlled laboratory environment:
 - ◆ CME speed and direction are known,
 - ◆ Can vary only one parameter.
 - We tested the Fixed-Phi and Point-P approximations.
 - We devised a new approximation which fits better our simulated CME and is important at large elongation angles (beyond 40°).
 - Lack of fast/wide CMEs may explain why fitting method work so well so far.
- ☼ Thanks to NASA and NSF for funding.